Large−area reflection grating spectrometer for the Constellation−X mission: Grating/CCD Technology Status

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The Role of a Reflection Grating Spectrometer on Constellation−X

- The soft X−ray band is rich in spectral features: (K−shell of C, N, O, Ne, Mg, Si, S; L−shell of Fe, Ni). $\lambda/\Delta\lambda > 300$ required for unambiguous line identifications.

- For microcalorimeters, ΔE is constant. Thus $\lambda/\Delta\lambda$ falls linearly with energy and is insufficient at energies less than ~ 0.5 keV. In addition, the microcalorimeter efficiency is limited at low energies due to the incorporation of long wavelength blocking filters.

- For a dispersive spectrometer, $\Delta\lambda$ is approximately constant, so $\lambda/\Delta\lambda$ rises inversely with decreasing energy. For reflection gratings, the efficiency also increases at low energies due to increasing reflection efficiency. This is especially important for spectroscopy of sources at cosmological distances where key spectral diagnostics are redshifted down to low energies!

- The RGS and the microcalorimeter are very complementary. Inclusion of both provides a very powerful payload across the entire X−ray band!

Our baseline concept builds strongly on the rich heritage of our collective team members in the design and fabrication of grating and CCD instruments.

- The optical and mechanical designs are closest to those of the Reflection Grating Spectrometer on *XMM* (Columbia).
- The CCD and electronics designs are outgrowths of the SIS instrument on *ASCA* and the ACIS instrument on *AXAF* (MIT, Penn State).
- The grating fabrication methodology builds strongly on microfabrication techniques developed for the HETGS experiment on *AXAF* (MIT).

Nevertheless, tight constraints on spacecraft resources for Constellation−X present important new challenges.

- Grating Array: Factor 3 weight reduction per unit area required relative to XMM. New methods of grating mass production required to meet schedule.
- CCD Camera: Significant reduction in power and weight needed relative to ACIS. Improved low energy response with high yield.

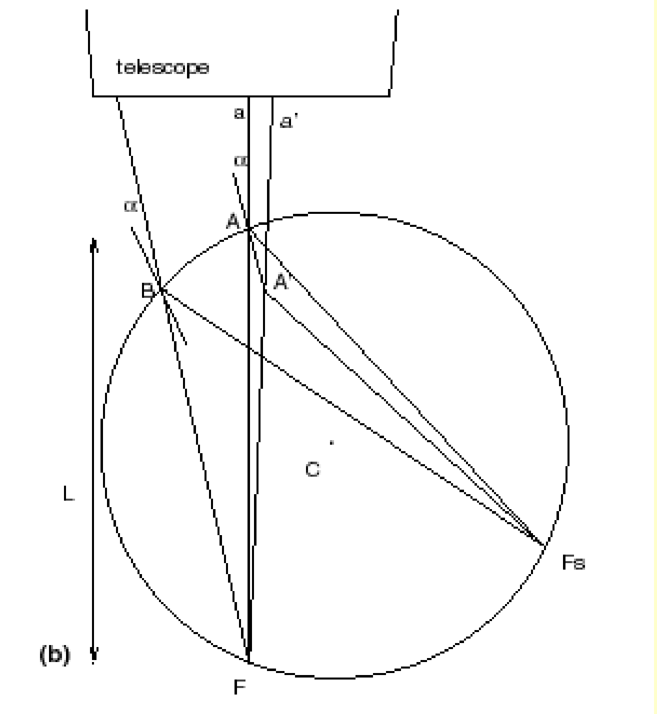
Baseline Design: Inverted Rowland Circle

* Essentially aberration free at all wavelengths.

* Design is compact − no additional length required behind the focus.

* Gratings require varied line spacing.

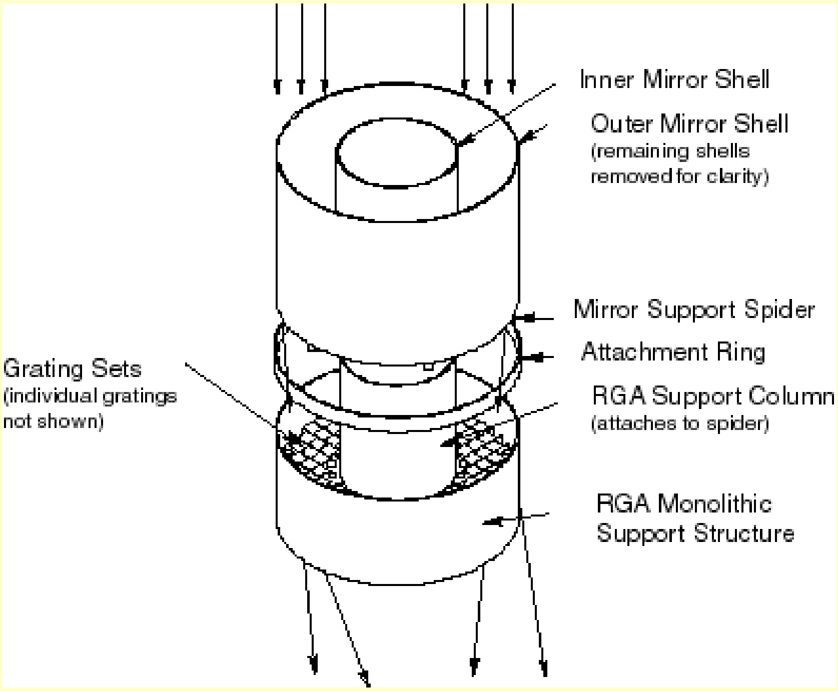
* Only cover outer half of the mirror shells at 50% throughput.
  Non−intercepted light goes to the microcalorimeter at the telescope focus.



Fabrication Approach: Reflection Grating Array

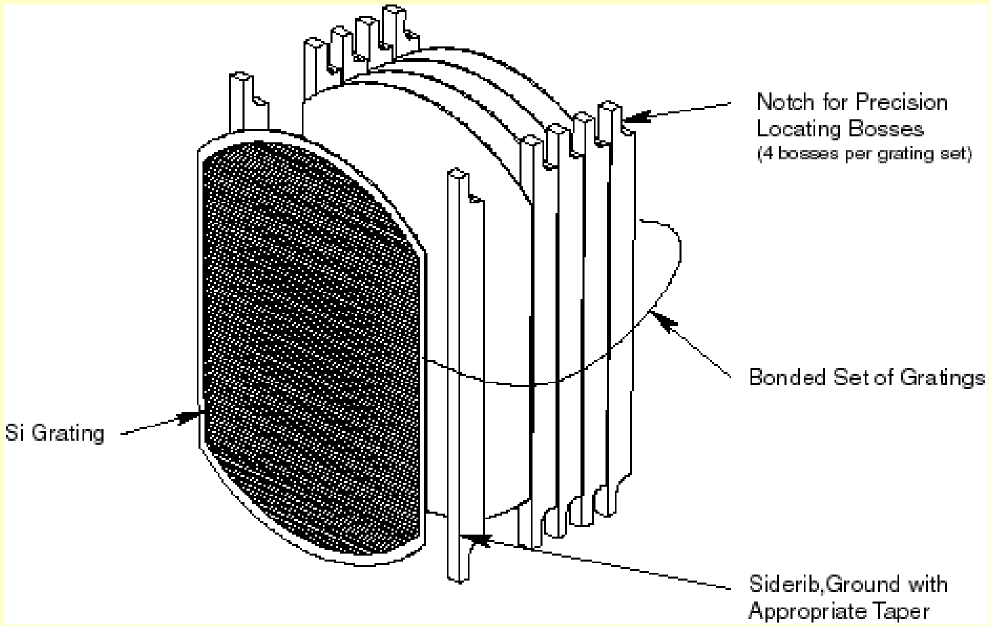
- For *XMM*, the gratings were epoxy replicated onto precision machined SiC substrates. This approach is too costly, time consuming, and heavy for Constellation−X.
- Instead, we propose to fabricate the gratings directly using interference lithography on graze−cut silicon wafers.
- Very thin (< 100 micron) grating “membranes” are produced using buried oxide silicon wafers. These are then mounted under uniform tension onto flat, lightweighted frames.
- The primary distortion is “twist”, which is removed by positioning the frames against four coplanar bosses, precision machined on alignment rails mounted to the structure.
- The integrating structure will consist of two concentric cylinders connected by a web that supports the rails. This will be integrally mounted to the telescope spider at the exit plane of the telescope.

Grating Fabrication: Integrating Structure Concept



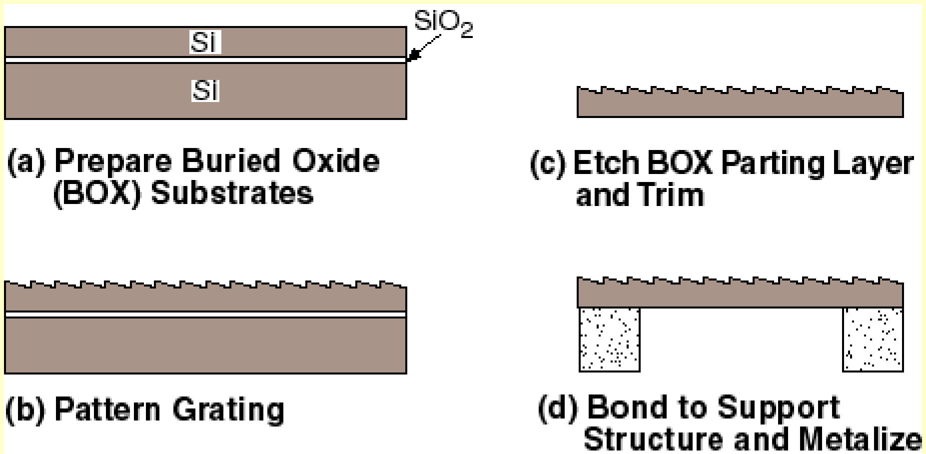
A sketch of a possible design for the integrating structure that supports the reflection grating array at the exit plane of the telescope. The mirror support spider and attachment ring might also be integral to the monolithic RGA support structure.

Grating Fabrication: Possible Modular Mounting Scheme



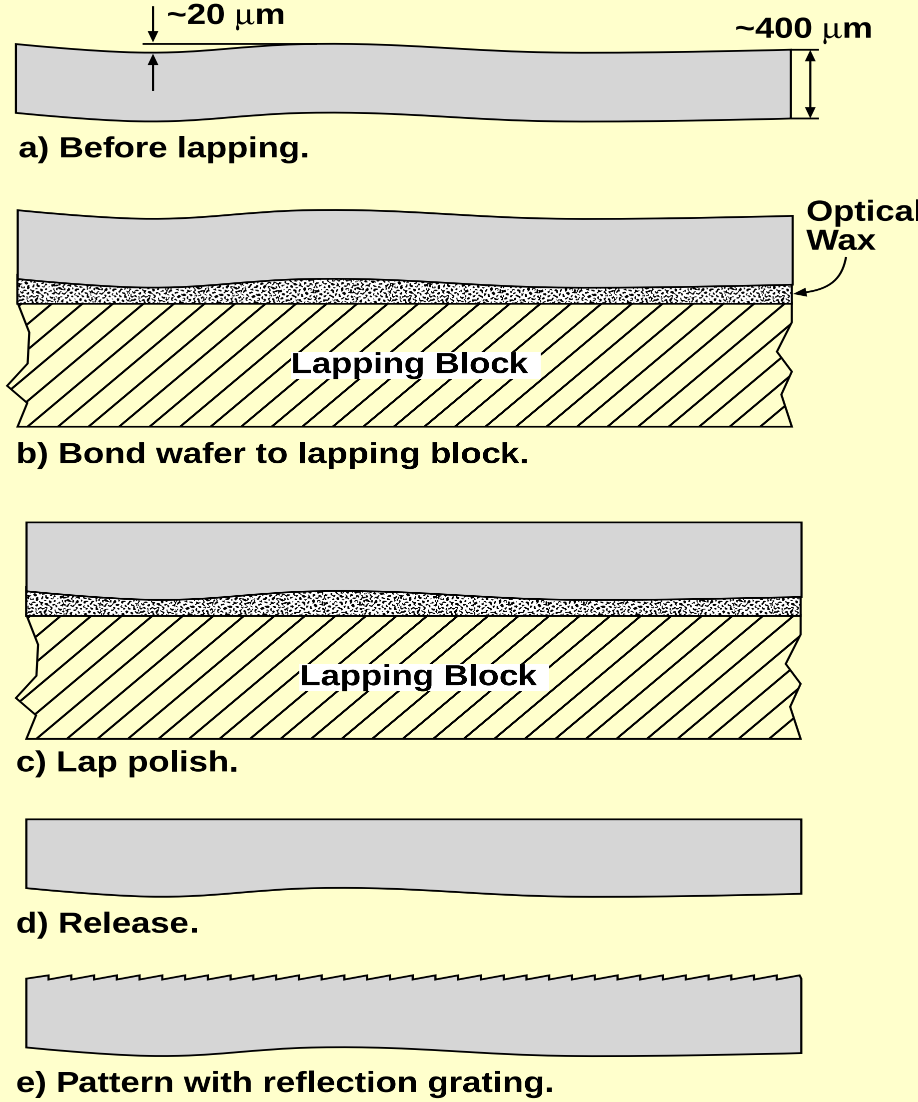
Possible approach to assembling and mounting gratings into sub−modules. The thin silicon gratings are bonded to precision ground sideribs with the correct taper to stack the gratings at the appropriate angles and separations. The ribs are notched for precision locating against reference bosses in the full−up assembly.

Grating Fabrication: Use of Buried Oxide Layer to Provide Thin Grating Membrane



Process overview for grating fabrication. Special buried oxide substrates are utilized which provide a simple and accurate way of thinning the grating.

Reflection Grating Fabrication Process Overview



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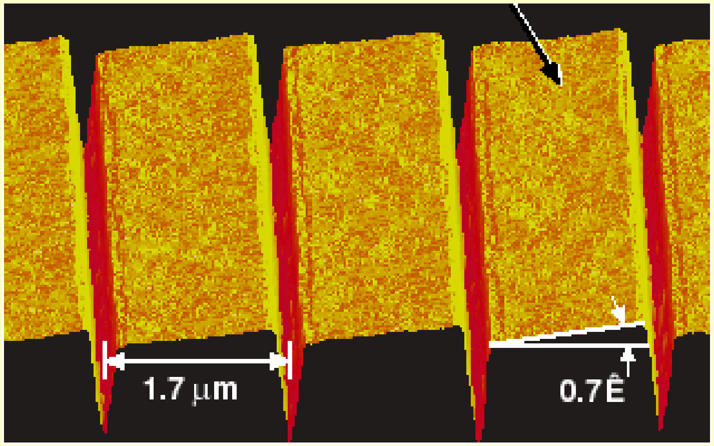
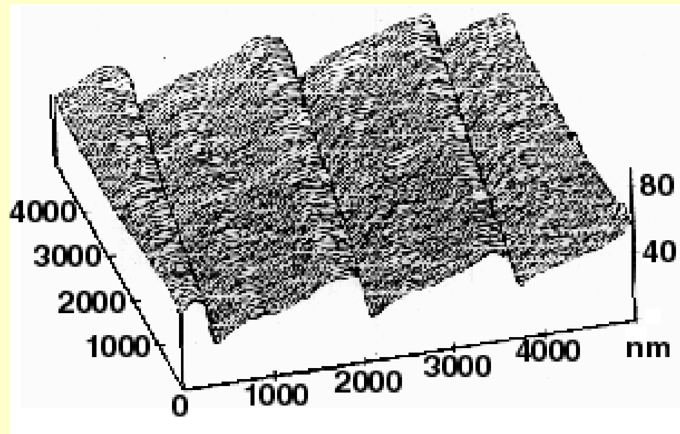
Grating Fabrication: Comparison of Silicon Etched and Mechanically Ruled Master Gratings





Left: Atomic force micrograph of an etched silicon reflection grating, produced as a Constellation−X prototype using the technique illustrated on the previous slide. The surface roughness is less than or of order 4 Angstroms.

Right: A scanning tunneling micrograph of a prototype reflection grating produced for *XMM* via mechanical ruling on a gold surface. Notice the significantly coarser groove profile.

Fabrication Approach: CCD Camera

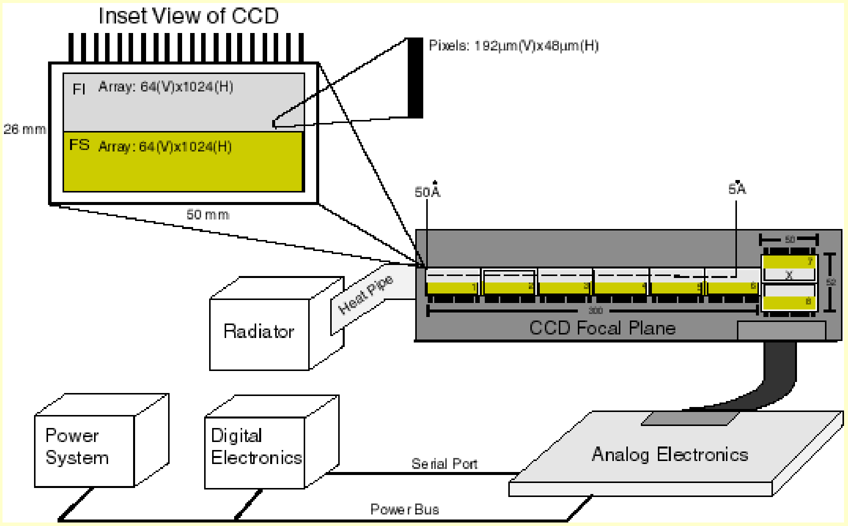
* X−ray CCDs are an established technology. However, Constellation−X requirements on weight and power, coupled with unique aspects of the RGS readout application, are not compatible with existing off−the−shelf devices.

* We propose to develop a novel "resistive−gate" CCD format. Significant advantages of this design include:

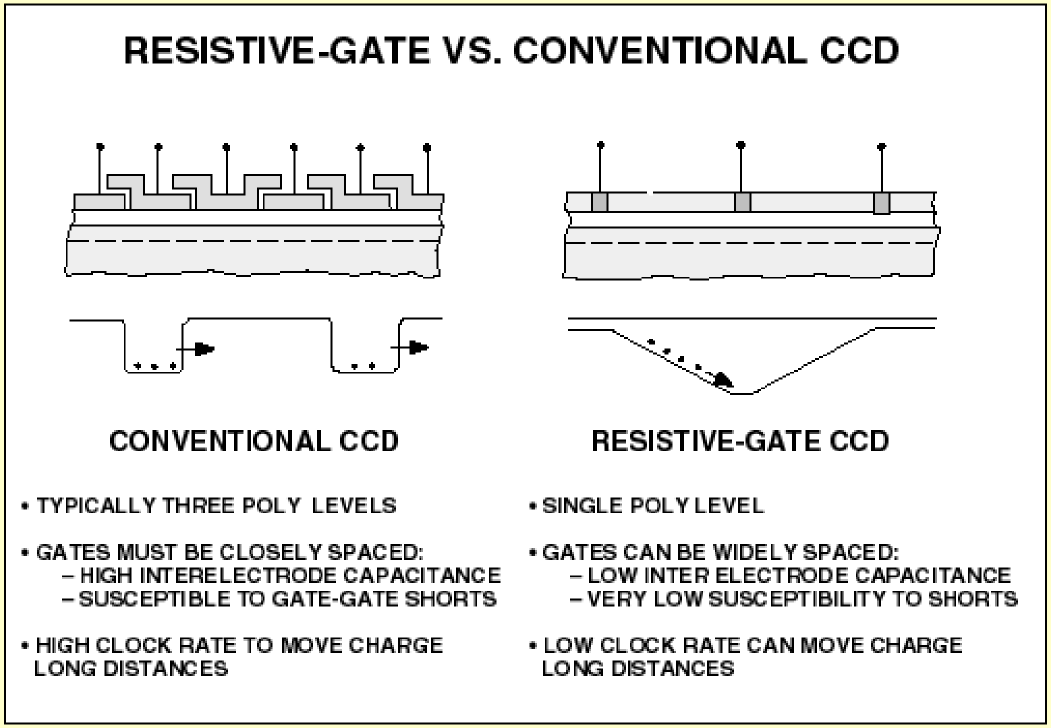
- Rectangular pixel geometry. Optimally suited to RGS image profiles.
- Low clocking power levels. 10−20 times lower than conventional MOS devices.
- High yield. Two times fewer processing steps. Immunity to interlevel shorts.
- Excellent readout noise. Two electrons rms at 100 kpix/s data rate.
- Intrinsic radiation hardness. Sensitive regions represent < 5% of the device area.
- Good low energy quantum efficiency. Reduced overlying gate structure implies only 300 − 500 Angstroms of polysilicon covering depletion region.

Baseline Design: CCD Camera

- 5 − 60 Angstrom band covered with six 50 mm X 26 mm chips.
- Each chip includes image and store regions with 64(V) X 1024(H) pixel formats.
- Rectangular pixels exploit RGS imaging geometry.
- Zero order light intercepted with two additional chips. Provides a low energy, wide field imaging camera, complementary to the microcalorimeter.

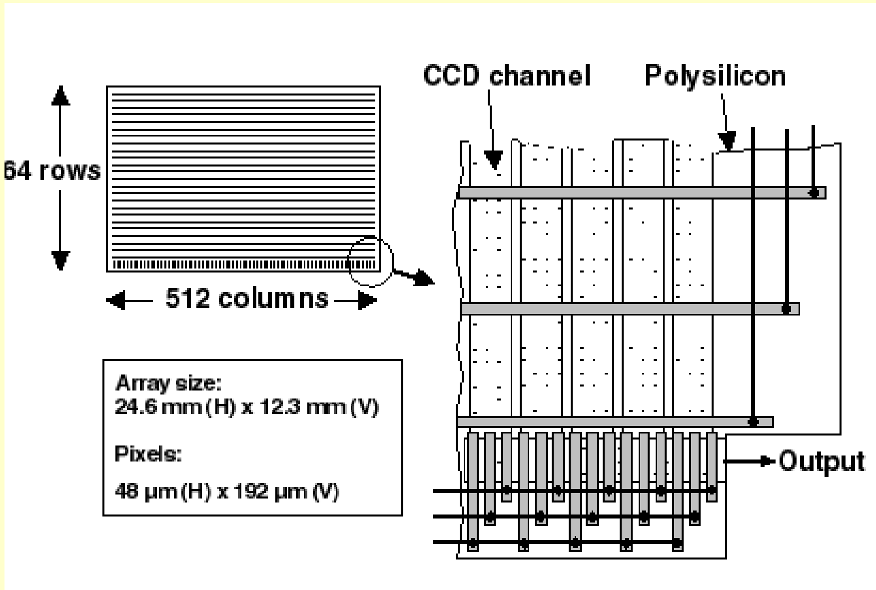


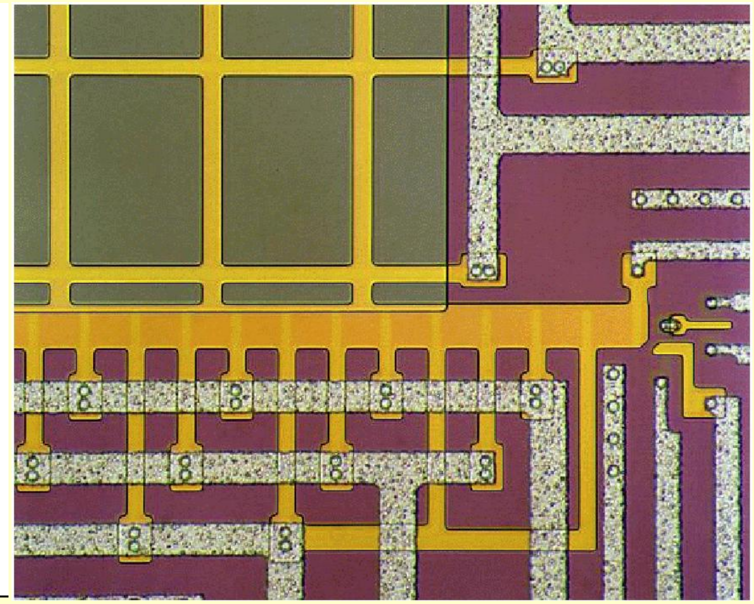
CCD Fabrication: Comparison of Conventional and Resistive−Gate CCD Formats



A comparison of the basic gate designs for a conventional three−phase CCD *(left)* and a resistive−gate CCD *(right)*.

CCD Fabrication: Layout of Prototype CCD





Prototype of RGCCD under development at MIT. The device has the same pixel design as that proposed for Constellation−X, but has one quarter as many pixels. On the right is an electron micrograph of this device showing the RG structure and the serial register.

Priorities for Grating/CCD Technology Development (first rank − 70% resources)

- Find out how to produce thin (~300μm) grating substrates that are flat (1 wave over 200mm):
  - Plasma Assisted Chemical Etching, Magneto−Rheological Lapping are less appropriate than previously hoped. (Possibly useful for finishing)..
  - Block lapping (wax adhesive) may work, if wax CTE values can be matched to substrate CTE.
- Develop scanning beam system for fabrication of non−umiform ruling densities in future graing production.
- Comparative study on grating mass production (fabricated gratings) vs. advanced replication techniques (fabricated masters).

Priorities for Grating/CCD Technology Development (second rank−30% resources)

- Spectrometer system integration: Grating assembly paper study including modular mounting model.
- System definition:
  - RGCCD camera/electronics system definition:
    - Mass budget.
    - Thermal budget.
    - Volume budget.
  - Grating assembly system definition:
    - Mass budget.
    - Thermal budget.
    - Volume envelope.

Priorities for Grating/CCD Technology Development (contingent on add’l funding)

- RGCCD development program:
  - Initial device characteristics study.
  - Charge transport/CTI.
  - Efficiency/thickness of depleted volume.
  - Low energy QE/RG transparency.
  - Spectral resolution/event characteristics.
  - Radiation damage tests/soft protons.
  - Practical limits to "adjusting" gate electrical properties.

Grating prototype measurement results

Fabricated Si (111) faceted grating (below); angular scans of diffraction efficiency measured at two energies (right).